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The intra- and inter-tester repeatability of radiographic elbow incongruity grading is high in chondrodystrophic dog breeds

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Abbreviations: INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.

Abstract

Elbow incongruity is a form of elbow dysplasia that causes osteoarthritis, pain and lameness, and is common in chondrodystrophic dog breeds. The objective of this retrospective secondary analysis study was to evaluate the intra- and interobserver repeatability of a novel radiographic incongruity grading system for assessing elbow incongruity in three chondrodystrophic dog breeds – the dachshund, Skye terrier and Glen of Imaal terrier. We conducted an observer agreement study that included 220 mediolateral antebrachial radiographs from 110 dogs with the elbow in 90° flexion. The radiographs were independently assessed by three observers at three time points, using a four-stepped grading scale. The proportion of agreement and Kappa coefficient were calculated. Both the intra- and interobserver proportions of agreement were substantial when three grades were required to be identical (0.705–0.777 and 0.609, respectively), and almost perfect for two identical grades (0.991–1.000 and 0.991, respectively). Some differences in repeatability between breeds were noted; specifically, the intraobserver repeatability was higher in the dachshund, and the interobserver repeatability was lower in the Glen of Imaal terrier. Our study showed that the radiographic imaging protocol and INC grading system has high repeatability when assessing elbow incongruity in chondrodystrophic dog breeds.

Introduction

Chondrodystrophy is a breed-characterizing trait caused by a *fgf4* retrogene, which affects dog breeds such as the dachshund, Glen of Imaal terrier and Skye terrier.[1] The characteristic short and curved front legs – which are also included in the breed standards of some of these breeds – is caused by blunted growth of the long bones[1]. Additionally, premature closure of the distal ulnar growth plate is also recognized as a common finding in some chondrodystrophic breeds.[2,3] This causes asynchronous growth of the radius and ulna, which is recognized as an etiology for elbow incongruity. This form of elbow dysplasia[3–5] is common in the Skye terrier, but for most chondrodystrophic breeds the prevalence is unknown.[2,3] In addition to elbow incongruity, the short ulna may cause the radius to bend craniocaudally and mediolaterally during growth, which is clinically described as multiplanar angular deformity of the antebrachium and valgus deformity of the carpal joint.[3–7] Elbow incongruity is associated with osteoarthritis, pain and lameness during growth and adulthood.[2,3]

Currently, the screening protocol used by the International Elbow Working Group (IEWG) and Orthopedic Foundation for Animals (OFA) is not optimal for detecting elbow incongruity in chondrodystrophic breeds.[8,9] It is only able to detect the most severely incongruent elbows and osteoarthritic changes of the elbows.[8,10,11] Lappalainen et al. (2016) proposed a novel grading system for elbow incongruity in chondrodystrophic dog breeds.[2] The radiographic protocol is based on images obtained with a 90° flexion of the elbow, with the x-ray beam centered mid-radius such that the whole antebrachium (including the carpal joint) is visible in the image.[2] However, the repeatability of this novel grading system has not been tested, although such studies should be carried out to assess the intra- and interobserver agreement. The objective of our study was to evaluate the intra- and interobserver repeatability of the grading system for elbow incongruity in chondrodystrophic dog breeds. We hypothesize that the grading system is repeatable both within and between observers.

Methods

This was a retrospective secondary analysis evaluating observer agreement[12] using mediolateral antebrachial radiographs of chondrodystrophic dogs, originally taken for another research project that had been approved by The National Animal Experiment Board in Finland (ESAVI/9184/04.10.07/2014). Dachshunds, Skye terriers and Glen of Imaal terriers of 1–10 years of age and no history of orthopaedic surgery or a condition that would increase the risk of sedation were eligible for the study and were approved by a qualified veterinarian. These images had been acquired for the other research project using the imaging protocol introduced by Lappalainen et al. (2016).[2] The images were acquired using computed radiography with an automatic exposure detector, imaging plates and reader (FUJIFILM FCR XG-1 CR-IR 346RU, Fuji Photo Film CO., LTD. 26-30, Nishiazabu 2-chome Minato-ku Tokyo 106-8620, Japan). S-values of 100-300 were targeted to ensure image quality. One of the observers was involved in supervising the acquisition of the radiographs in the original study and was aware of the dogs signalment and history regarding lameness before the anonymization process was performed for the images. The two other observers were only provided anonymized radiographs. The DICOM-images were anonymized and randomized using computerization. The radiographs were independently graded by three observers (A, B and C) who had 12, 1 and 7 years of experience in veterinary radiology, respectively. Three randomized sets of the radiographs were produced for each observer; each observer graded each image three times. The radiographs were assessed with image analysis freeware (OsiriX MD 9.0 or Horos DICOM viewer v. 2.1.1). Magnification and windowing were allowed as necessary to ensure precise measurements. The grading was performed using the 4-stepped grading system (INC0–INC3) described by Lappalainen et al. (2016; Table 1). Prior to the actual grading, the observers familiarized themselves with the method through discussion with each other. Ten randomly chosen radiographs from the set were then given to each evaluator in order to get accustomed to the grading. Finally, the results were discussed to ensure that all observers were confident with the grading protocol. The first actual grading was done two weeks after the familiarization process. To avoid recall bias, the three gradings were carried out over a 12-week time period, with at least two weeks between gradings. Once a grade was decided, second-look revisions for the image were not allowed.

All the statistical tests were selected and completed by a professional biostatistician (MSc in biostatistics) with over 10 years' experience conducting clinical and non-clinical trials.

Intraobserver repeatability was calculated as the proportion of images in which the observer assigned the same INC grade (proportion of agreement) with 95% confidence intervals (CI). The mode of the three ratings for each individual observer was used to calculate the interobserver agreement (with 95% CIs). The interobserver proportion of agreement was calculated for full agreement (all observers agree), and also for pairwise agreements between each pair of observers. Furthermore, the proportion of radiographs where at least two out of three gradings were identical was calculated for both intra- and interobserver agreement. In addition, Fleiss' Kappa coefficients for the three-way agreement within and between the observers were calculated, and weighted Kappa coefficients (with 95 % CIs) were calculated for the pairwise agreement between the observers. When the Kappa values were evaluated, the following ranges were used: less than zero was considered to have less than a chance agreement; 0.01–0.20 was slight agreement; 0.21–0.40 was fair agreement; 0.41–0.60 was moderate agreement; 0.61–0.80 was substantial agreement; and 0.81–1.00 was almost perfect agreement.[13] For the purpose of this study, these categories were also applied to the proportion of agreement values. Statistical analyses were performed using commercially available software (SAS® System for Windows, version 9.3, SAS Institute Inc., Cary, NC, USA; and R for Windows, version 3.4.2, R Foundation for Statistical Computing, Vienna, Austria).

Results

Digital radiographs from 30 dachshunds, 53 Glen of Imaal terriers and 27 Skye terriers were available for evaluation. The images included both the left and right elbow radiographs of each dog, yielding a total of 220 radiographs from the 110 dogs. All INC grades were represented in the radiographs. INC1 was the most frequent grade for each observer at each time point, and INC3 was the most uncommon. Table 2 reports the frequencies of each grade assigned by each observer at each time point.

The intraobserver proportion of agreement was substantial (0.705–0.777) when the requirement was for three grades to be identical. When the requirement was for two grades to be identical, the agreement was almost perfect (0.991–1.000). The intraobserver Fleiss' Kappa values also suggested substantial agreement (0.623–0.690) for each of the observers when three identical grades were required (Table 3). The interobserver proportion of agreement was substantial (0.609; 95% CI 0.54–0.67) when all three observers were included; if at least two observers were required to agree on the same grade, the proportion was almost perfect (0.991). The interobserver Fleiss' Kappa value was moderate (0.502; 95% CI 0.45–0.56) when all three observers were required to agree, and moderate to substantial (0.568–0.617) for the pairwise analyses between observers (Table 4). An example of an elbow with high intra and interobserver agreement is shown in Figure 1 and an example of an elbow with low agreement is shown in Figure 2.

When analyzed by breed, the intraobserver proportion of agreement was highest for the dachshund (0.767–0.850) for all observers. The agreement was lower, and roughly similar for the Glen of Imaal terrier (0.651–0.745) and Skye terrier (0.667–0.759; Table 5). The interobserver proportion of agreement by breed was moderate to substantial, ranging from 0.557–0.717. Based on the Fleiss' Kappa coefficient, agreement was moderate for both the Skye terrier (0.528) and dachshund (0.570), but only fair for the Glen of Imaal terrier (0.400; Table 6).

Discussion

Our study showed that the novel grading method for assessing elbow incongruity among chondrodystrophic dogs had excellent intraobserver proportion of agreement. When two grades (out of the three grading time points) were required to be identical, two of the observers had a perfect intraobserver agreement, and the third observer reached an almost perfect agreement (Table 3). The intraobserver agreement was substantial even when grades from all three time points were assessed. The interobserver agreement was almost perfect between two observers, and substantial among all three observers.

Based on our review of the literature, there are no repeatability studies available for comparisons of radiographic grading of elbow dysplasia in dogs. However, according to repeatability studies of another prevalent radiographic screening method – the Fédération Cynologique Internationale (FCI) hip dysplasia scoring system – proportions of agreement have ranged from 46.3 to 71.3%, and Kappa values from 0.46 to 0.76.[14–16] Thus, the interobserver consistency of INC found in our study appears to be higher than what has been reported for hip dysplasia. The high agreement for the INC grading system noted in our study may reflect the objectivity of the measurement-based protocol, compared to the subjective nature of the hip dysplasia measurement and FCI score.

Regarding the observer-related factors that may contribute to the grading consistency, prior experience in radiology could be assumed to affect repeatability, as supported by Verhoeven et al. (2009).[17] In our study, however, the intraobserver repeatability and pairwise analyses were almost similar between all observers, regardless of experience. This may be a result of the observers having the opportunity to get accustomed to the grading system before applying it. As subjectivity can never be completely eliminated, there is always some inherent fluctuation within and between individuals, leading to a higher likelihood of disagreement with increased grading repetitions. Accordingly, we observed a slightly lower repeatability when all three grades were required to be identical, compared to when only two were required.

When the images were grouped by breed, the agreement was lower in the Glen of Imaal terrier in the intraobserver agreement analyses in two of the observers (A and B). The agreement was also lower for the Glen of Imaal terrier in the breed-specific interobserver analysis. It is possible that this is due to the slightly larger size – and thus longer limbs – of the Glen of Imaal terrier. Specifically, as the x-ray beam is centered to the mid-radius, the longer antebrachium requires the beam to be positioned farther away from the joint. As this study aimed to assess the repeatability of a previously established imaging protocol, we did not make changes to the positioning of the patient or the radiographic beam regarding the protocol described in the earlier study by Lappalainen et al. 2016. However, the effect of beam centering for recognizing elbow incongruity has been studied by Murphy et al. (1998), who found that a congruent joint will not appear incongruent even if the radiographic beam is not centered directly on the elbow.[18] This was further supported in a later study by Blond et al. (2005), who showed that only a proximal displacement affected the recognition of normal elbows – a beam misalignment as large as 3 cm away from the center of the joint did not affect the recognition of incongruity.[10] Thus, it is unlikely that the larger size of the Glen of Imaal terrier would explain the lower repeatability in this breed, but can be considered a limitation of the imaging protocol for non-chondrodystrophic dog breeds. However, one breed-related factor that could explain the noted difference in repeatability might be the amount of angular deformity in the forelimb, which is likely to vary between breeds. The deformity may make it difficult to position the joint in such a way that the medial and lateral border of the ulnar joint surface would overlap perfectly in the image. The resulting double silhouette could have an effect on measuring the joint space. Additionally, if the joint space measures very close to the boundary of two grades, very small variations (such as a tenth of a millimeter) between the measurements may result in a different INC grade. Subjectively, this could be the case especially between grades 0 and 1. The breeds selected for our study may represent different frequencies of these borderline cases of the INC grades.

Although this study highlighted the importance of repeatability in INC grading, it is not without limitations. For example, the frequencies of the different INC grades were not distributed equally. The most dominant grade was INC1, comprising over half of the samples. Subjectively, among the cases where demarcation between grades may have caused uncertainty, the most common were borderline cases between INC0 and INC1. In the more severely affected cases, the joint space might be easier to measure even in the presence of other deformities, especially when the joint space would be wider than 3 mm. Therefore, it could be argued that if the study population would have included a larger proportion of more severe cases (i.e. INC2 and INC3), the repeatability could possibly be higher than what we report in the current study.

The INC grading as such does not take into account possible signs of osteoarthritis, which should obviously be added to the protocol if used for screening purposes. Actually, the screening protocol of the Finnish Kennel Club has incorporated osteoarthritis into the protocol, and a dog with signs of degenerative joint disease cannot get INC grades 0 or 1.

In conclusion, our study showed that the radiographic grading of elbow incongruity by the INC grading system had good intra- and interobserver repeatability in chondrodystrophic breeds such as the dachshund, Glen of Imaal terrier and Skye terrier. This would make the INC grading system a suitable method for screening elbow incongruity in these breeds. However, as this study only aims to assess repeatability of the grading system, any recommendations on which grades should be considered acceptable for each breed would require further investigations.

List of author contributions

Category 1

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(b) Acquisition of Data: Pulkkinen HSM, Reunanen VLJ, Hyytiäinen HK, Lappalainen AK

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Category 2

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Category 3

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Table 1. The incongruity-grading system used for scoring elbow incongruity (as described by Lappalainen et al. 2016).[2]

Grade	Definition
INC0 (normal)	Even and narrow joint space; the width of the humeroulnar joint space measures < 1 mm.
INC1 (mild)	The width of the humeroulnar joint space measures 1–2 mm.
INC2 (moderate)	The width of the humeroulnar joint space measures 2–3 mm.
INC3 (severe)	The width of the humeroulnar joint space measures > 3 mm.

INC, incongruity grade.

Table 2. Frequencies of incongruity grades, by observer and measurement time point, for 220 elbow joint images (110 dogs) in three chondrodystrophic dog breeds.

Grade	**Observer**	**A**			**B**			**C**		
	Measurement time point	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
INC0		51	32	26	66	60	64	25	22	34
INC1		138	157	166	121	125	120	132	156	135
INC2		25	25	23	26	28	29	54	38	45
INC3		6	5	5	7	7	7	9	4	6

INC, incongruity grade.

Table 3. Intra-observer proportion of agreement and Fleiss' Kappa of incongruity grades for 220 images of elbow joints from 110 dogs representing three chondrodystrophic dog breeds.

Observer	**PA**	**Lower 95 % CI**	**Upper 95 % CI**	**Kappa**	**Lower 95 % CI**	**Upper 95 %CI**
Three ratings identical						
A	0.777	0.72	0.83	0.690	0.635	0.745
B	0.714	0.65	0.77	0.678	0.623	0.733
C	0.705	0.64	0.76	0.623	0.568	0.677
At least two ratings identical						
A	1.000	0.98	1.00			
B	1.000	0.98	1.00			
C	0.991	0.97	1.00			

INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.

Table 4. Interobserver proportion of agreement and weighted Kappa of incongruity grades for 220 images of elbow joints from 110 dogs representing three chondrodystrophic dog breeds.

Agreement in question	**PA**	**Lower 95 % CI**	**Upper 95 % CI**	**Kappa**	**Lower 95 % CI**	**Upper 95 % CI**
All three agree	0.609	0.54	0.67	0.502*	0.448	0.557
At least two agree	0.991	0.97	1.00			
A vs. C	0.759	0.70	0.81	0.583	0.481	0.686
A vs. B	0.755	0.69	0.81	0.617	0.526	0.708
B vs. C	0.695	0.63	0.76	0.568	0.477	0.660

**Fleiss' Kappa; INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.*

Table 5. Intra-observer proportion of agreement and Fleiss' Kappa of incongruity grades for three identical gradings of 220 images of elbow joints from 110 dogs representing three chondrodystrophic dog breeds, analyzed by breed.

Observer	**Breed**	**PA**	**Lower 95 % CI**	**Upper 95 % CI**	**Kappa**	**Lower 95 % CI**	**Upper 95 % CI**
A							
	Glen of Imaal terrier	0.745	0.65	0.82	0.614	0.515	0.714
	Dachshund	0.850	0.73	0.93	0.727	0.619	0.835
	Skye terrier	0.759	0.62	0.87	0.727	0.611	0.844
B							
	Glen of Imaal terrier	0.651	0.55	0.74	0.562	0.463	0.662
	Dachshund	0.800	0.68	0.89	0.763	0.657	0.868
	Skye terrier	0.741	0.60	0.85	0.720	0.613	0.828
C							
	Glen of Imaal terrier	0.689	0.59	0.78	0.570	0.486	0.653
	Dachshund	0.767	0.64	0.87	0.663	0.555	0.772
	Skye terrier	0.667	0.53	0.79	0.595	0.464	0.726

PA, proportion of agreement; CI, confidence interval.

Table 6. Interobserver proportion of agreement and Fleiss' Kappa of incongruity grades for three identical gradings for 220 images of elbow joints from 110 dogs representing three chondrodystrophic dog breeds, analyzed by breed.

Breed	**PA**	**Lower 95 % CI**	**Upper 95 % CI**	**Kappa**	**Lower 95 % CI**	**Upper 95 % CI**
Glen of Imaal terrier	0.557	0.46	0.65	0.400	0.306	0.495
Dachshund	0.717	0.59	0.83	0.570	0.465	0.675
Skye terrier	0.593	0.45	0.72	0.528	0.410	0.645

INC, incongruity grade; PA, proportion of agreement; CI, confidence interval.

Figure 1A. Mediolateral radiograph of the antebrachium showing an example of an elbow with high intra and intertester agreement of incongruity grade showing a single measurement made with the imaging software. All three observers graded the elbow as INC1 on each of the three gradings. The image was acquired using computed radiography with an automatic exposure detector (FUJI imaging plates, FUJIFILM reader, 44 kV; 4,0 mAs, S-values of 100-300).

Figure 1B. Zoomed and cropped version of the same radiograph as Fig. 1A, centered over the humeroulnar joint space.

Figure 2A. Mediolateral radiograph of the antebrachium showing an example of an elbow with low intra and intertester agreement of incongruity grade. The elbow was graded INC0 three times and INC1 six times. The image was acquired using computed radiography with an automatic exposure detector (FUJI imaging plates, FUJIFILM reader, 44 kV; 4,0 mAs, S-values of 100-300).

Figure 2B. Zoomed and cropped version of the same radiograph as Fig. 2A, centered over the humeroulnar joint space.